High-Performance Buildings for High-Tech Industries

Guidelines for Manufacturers' Testing to Benchmark Data Center UPS Efficiency

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Research Sponsored by:
Public Interest Energy Research (PIER),
California Energy Commission

and Administered by
California Institute for Energy Efficiency (CIEE)

June 7, 2004

Background

Prior benchmarking efforts led by Lawrence Berkley National Lab (LBNL), as part of a data center energy efficiency roadmap development process, have identified uninterruptible power supply (UPS) systems as a large opportunity for energy savings (http://datacenters.lbl.gov).

UPS systems operate continuously and constantly consume electrical energy to provide standby power and power conditioning for information technology (IT) equipment and some facility systems. The efficiency of UPS systems is affected by the load conditions under which they operate. In general, the efficiency of a UPS system drops off significantly at part-load conditions, which are typical of how most data centers operate. Redundancy strategies can also impact UPS efficiency depending upon how they are implemented. Likewise, system losses, which materialize as heat within the data center or facility, add to the cooling load (especially during summer months), resulting in even higher energy costs and poorer facility efficiency.

On behalf of LBNL, Electric Power Research Institute Power Electronics Applications Center (EPRI PEAC) and Ecos Consulting are conducting an in-depth assessment of the "real-life" efficiency of data center UPSs. This effort will lead to establishing a credible benchmark of UPS efficiency that will help state energy commissions, EPA's Energy Star Program, and other state and federal energy efficiency programs to develop voluntary or mandatory energy efficiency standards/labeling criteria. A credible benchmark will also allow interested electric utilities to provide incentives for higher efficiency UPSs.

Purpose

The purpose of this guideline is to provide instructions to manufacturers of data center UPS systems on how to measure and report the efficiency of their UPS systems under different linear and nonlinear loading conditions. Typically, efficiency values quoted in manufacturers' specifications are for nominal load conditions, which, in most cases, do not represent "real-life" loading conditions.

The development of energy-efficiency indicators for UPSs largely depends on a credible set of data that will allow comparison of "real life" efficiency to "quoted" efficiency, as reported by manufacturers in product specifications.

This guideline was created to facilitate the collection of data from UPS manufacturers as part of their "*Routine tests,*" "*Type tests,*" or "*Factory witness tests/on-site tests.*" It is based on procedures described in IEC 62040-3, *Uninterruptible power systems (UPS) – Part 3: Method of specifying the performance and test requirements*. This IEC standard has also been adopted by the National Electrical Manufacturers Association (NEMA) as part of *NEMA Standards Publication PE-1 2003, Uninterruptible Power Systems (UPS) – Specification and Performance Verification*.

Through a separate guideline, *Guidelines for Field Data Collection to Benchmark Data Center UPS Efficiency,* field data from data center environments is being gathered as another part of this study.

Description of Manufacturer Testing

The following excerpts from the IEC/NEMA standards define the different of types of manufacturer tests that are typically done on UPS Systems:

Section 6.1.1, IEC 6240-3 Type tests

The tests shall be performed to verify that the design of the product is appropriate to meet performance requirements specified in this standard and/or those specified separately by the manufacturer or purchaser for special applications.

NOTE – For UPS in series production, some of the type tests may be repeated at specified intervals on a specified number of samples to verify that the quality of the product is maintained.

Section 6.1.2, IEC 6240-3 Routine tests

Routine tests shall be performed on each UPS or UPS functional units, if they are shipped separately, before delivery, to verify that the requirements of this standard are met. Due to the diversity of the UPS types and construction, it shall be at the manufacturer's discretion as to how and which tests are performed to prove the functionality of a complete UPS design.

Section 6.6, IEC 6240-3 Factory witness tests/on-site tests

It shall be a matter of agreement between the manufacturer/supplier and the purchaser as to which tests are to form part of the purchase contract, as this will be dependent upon the degree to which the UPS or UPS functional units can be tested by the manufacturer prior to delivery. UPS may be type or routine tested in the factory as a complete UPS and less extensive operational tests with batteries and load are performed on site. Alternatively, routine tests in the factory may be restricted to UPS functional units or combinations of them. The final test on site then replaces the UPS routine factory test.

UPS Efficiency Test

A "*UPS Efficiency test"* is recommended in the IEC standard as part of routine tests and factory witness tests/on site tests if mutually agreed upon by the manufacturer/supplier and the purchaser. Section 6.6.11 provides generic guidance on the protocol for UPS efficiency test.

Section 6.6.11, IEC 6240-3 UPS efficiency test

UPS efficiency shall be determined by the measurement of the input and output active power in normal mode of operation and available load.

In addition to this general guideline provided in the IEC standard, the following sections provide more specific guidance for UPS efficiency test protocol and data reporting forms.

Load Characteristics

We recommend testing of UPS efficiency using a linear load with 0.8 power factor and a reference nonlinear load, as described in IEC 6240-3 (See Appendix A).

Loading Points

We recommend testing of UPS efficiency at the following loading levels. Loading level is based on UPS output power rating.

- 0% (No Load)
- 10%
- 20%
- 50%
- 75%
- 100%

UPS System Definition

We recommend testing efficiency of the entire UPS system, which can include input/output filters, input/output isolation transformer as part of the UPS system.

Data Reporting

Please turn to the Information Collection Sheets provided at the end of this document and answer the following sections:

- Part 1. Meter Accuracy
- Part 2. UPS Technology
- Part 3. Company/Contact Information
- Part 4. Nameplate Information
- Part 5. UPS System Description
- Part 6. UPS Efficiency Data (for three phase UPS)
    1. Linear Load Test Data
    2. Non-Linear Load Test Data
- Part 7. UPS Load Trend Data

Information Collection Sheets

Part 1. Meter Accuracy. For efficiency measurements, it is important to note the accuracy of the meters (including the transducers) that are being used to measure electrical parameters. Please provide information regarding the overall accuracy of the input and output power measurement system, including the type of instrument used and their calibration date in Table 1 below.

Table 1. Meter Accuracy Information

Instrument Used	
Model Number	
Serial Number	
Overall Accuracy	
Date of Last Calibration	

Part 2. UPS Technology. The UPS technology describes some of the typical circuit arrangements in use and their mode of operation as defined by the IEC. Please circle the type of UPS technology being tested.

1. Static Double Conversion UPS
2. Static Line Interactive UPS
3. Static Stand-by UPS
4. Static Delta Conversion UPS
5. Rotary Flywheel Based UPS (low speed, < 5000 rpm)
6. Rotary Flywheel Based UPS (medium speed, 5000 rpm to 9999 rpm)
7. Rotary Flywheel Based UPS (high speed, > 10000 rpm)
8. Rotary Motor Generator Set-based UPS
9. Other (please describe): _____

   _____

   _____

Part 3. Company/Contact Information. Please fill in the appropriate information in Table 2 below.

Table 2. Company Contact Information

Name	
Title	
Date	
Company Name	
Address	
Phone Number	
Email Address	
Description of Business	

Part 4. Nameplate Information. If taking measurements from more than one UPS or system, please fill out a separate table for each one. Use Table 3 below as your template. Attach sheets as necessary.

Table 3. Nameplate Information (Template)

UPS Manufacturer	
Model Number	
Serial Number	
Rated Input Voltage	
Delta or Wye Connection	
Frequency	
INPUT	
Rated Input kVA	
Rated Input kW	
OUTPUT	
Rated ac Output Voltage	
Rated dc Output Voltage[1]	
Number of Phases	3
Specified Efficiency	

[1] For dc output UPS only.

Part 5. UPS System Description. Please circle one or more of the following items that could be part of the overall UPS system:

1. Input filter
2. Input Isolation Transformer
3. Output filter
4. Output Isolation Transformer
5. Other (please describe): _____

_____

_____

Part 6. UPS Efficiency Data (for a three phase UPS). Please fill in as many fields as possible. This will allow for crosschecking and verification of data. Please verify that batteries are fully charged before recording any information. The recommended loading level for data collection under linear and non-linear loading is 0%, 100%, 10%, 20%, 50%, and 75%. Twelve (12) charts are provided for this data collection process at these levels—six (6) for linear loading and six (6) for non-linear loading. Please fill in the respective loading level for each data collection effort. If data is collected at loading levels other than the percentages listed above, please record those levels.

Linear Load Test Data

Three-Phase UPS: Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Non-Linear Load Test Data

Three-Phase UPS: Non-Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Does the UPS contain an input filter? Yes No			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Does the UPS contain an output filter? Yes No			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Non-Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Does the UPS contain an input filter? Yes No			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Does the UPS contain an output filter? Yes No			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Non-Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Does the UPS contain an input filter? Yes No			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Does the UPS contain an output filter? Yes No			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Non-Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Does the UPS contain an input filter? Yes No			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Does the UPS contain an output filter? Yes No			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Non-Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Does the UPS contain an input filter? Yes No			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Does the UPS contain an output filter? Yes No			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

Three-Phase UPS: Linear Load Testing - _____ % Load

Electrical Parameter	Phase A	Phase B	Phase C
INPUT			
Input Voltage RMS			
Input Current RMS			
Input kVA			
Input Power kW			
Input Current THD (% of Fundamental)			
Input Voltage THD (% of Fundamental)			
OUTPUT[1]			
Output Voltage RMS			
Output Current RMS			
Output kVA			
Output Power kW			
Output Current THD (% of Fundamental)			
Output Voltage THD (% of Fundamental)			

[1]For dc output UPS only provide data for output voltage, current and power and fill in the cells for Phase A.

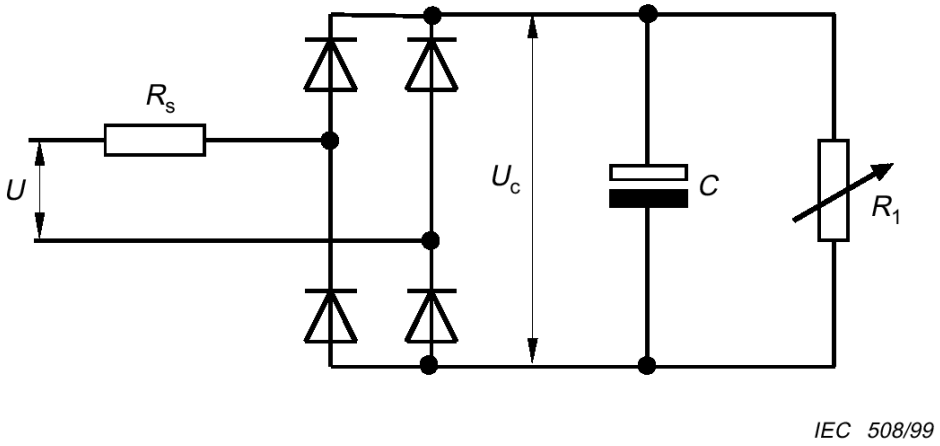
Part 7. UPS Load Trend Data. If input and output data is available for a period of time from the UPS software or another recording instrument please provide the following information for the data file and complete the table below.

Data file format	
Channel names	
Software name and version used for data viewing and analysis	
Can the data be exported into MS Excel format? Yes No	
Other recording instrument (other than UPS software)	

Appendix A (Excepts from Annex E of IEC 62040-3)

Reference non-linear load

To simulate a single-phase steady-state rectifier/capacitor load, the UPS is loaded with a diode rectifier bridge which has a capacitor and a resistor in parallel on its output. The total single-phase load may be formed by a single load as per figure E.1, or formed by multiple equivalent loads in parallel.



NOTE – Resistor R_s can be placed either on the a.c. or d.c. side of the rectifier bridge.

Figure E.1 – Reference non-linear load

Calculation method

U	Rated output voltage of UPS, r.m.s.
f	UPS output frequency in hertz
U_C	Rectified voltage
S	Apparent power across a reference non-linear load – power factor 0,7 i.e. 70 % of the apparent power *S* will be dissipated as active power in the two resistors R_1 and R_s .
R_1	Load resistor – set to dissipate an active power equal to 66 % of the total apparent power *S*
R_s	Series line resistor – set to dissipate an active power equal to 4 % of the total apparent power *S*

A ripple voltage of 5 % peak-to-peak of the capacitor voltage U_c corresponds to a time constant of $R_1 \cdot C = 7{,}5/f$.

From peak voltage, distortion of line voltage, voltage drop in line cables and ripple voltage of rectified voltage the average of the rectified voltage U_c will be empirically:

$$U_C = \sqrt{2} \text{ x } 0{,}92 \text{ x } 0{,}96 \text{ x } 0{,}975 \text{ x } U = 1{,}22 \text{ x } U$$

and the values of resistors R s , R 1 and capacitor C in farads will be calculated by the following:

$R_s = 0{,}04 \cdot U^2 / S$
$R_1 = U_c^2 / (0{,}66 \cdot S)$
$C = 7{,}5 / (f \cdot R_1)$
For dual frequency 50 Hz or 60 Hz, 50 Hz shall be used in the calculation. The capacitance value used shall be not less than the calculated value.

NOTE 1 – The voltage drop in the diode bridge is neglected.

NOTE 2 – Tolerances on calculated component values:

R_s : ±10 %

R_1 : to be adjusted during test to obtain rated output apparent power.

C : 0 to + 25 %

Test method

a) The reference non-linear load test circuit shall initially be connected to an a.c. input supply at the rated output voltage specified for the UPS unit under test.

b) The a.c. input supply impedance shall not cause a distortion of the a.c. input waveform greater than 8 % when supplying this test load (requirement of IEC 61000-2-2).

c) The resistor R_1 shall be adjusted to obtain the rated output apparent power (S) specified for the UPS under test.

d) After adjustment of resistor R_1, the reference non-linear test load shall be applied to the output of the UPS under test without further adjustment.

e) The test load shall be used, without further adjustment, whilst performing all tests to obtain parameters required under reference non-linear loading, as defined in the various clauses.

Connection for reference non-linear loads to UPS

a) For single-phase UPS, the reference non-linear load is used with apparent power *S* equal to the UPS rated apparent power up to 33 kVA.

b) For single-phase UPS rated above 33 kVA, the reference non-linear load is used with an apparent power *S* of 33 kVA, plus linear load up to the apparent and active power rating of the UPS.

c) For three-phase UPS rated up to 100 kVA designed for single-phase loads, three equal single-phase reference non-linear loads shall be connected either line-neutral or line-to-line, depending on UPS design.

d) For three-phase UPS rated above 100 kVA, the loads in accordance with item c) shall be used up to 100 kVA, plus linear load up to the apparent and active power rating of the UPS.